Report from Dagstuhl Seminar 13241

Virtual Realities

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Abstract

This report documents the program and the outcomes of Dagstuhl Seminar 13241 "Virtual Realities". The main goal of the five day seminar was to bring together leading experts and promising young researchers to discuss current challenges and future directions in the field of virtual and augmented reality. The seminar was organized as series of individual presentations and seven working groups. Abstracts of the presentations and working group reports are collected in this report.

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1 Executive Summary

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Virtual Reality (VR) is a multidisciplinary area of research aimed at interactive human computer mediated simulations of artificial environments. An important aspect of VR-based systems is the stimulation of the human senses – usually sight, sound, and touch – such that a user feels a sense of presence in the virtual environment. Sometimes it is important to combine real and virtual objects in the same real or virtual environment. This approach is often referred to as Augmented Reality (AR), when virtual objects are integrated into a real environment. Research in VR and AR encompasses a wide range of fundamental topics, including: 3D interaction, presence, telepresence and tele-existence, VR modelling, multi-model systems, and human factors. Typical VR applications include simulation, training, scientific visualization, and entertainment, whereas typical AR applications include computer-aided manufacturing or maintenance, and computer-aided surgery or medicine.

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The main goal of the seminar was to bring together leading international experts and promising young researchers to discuss current VR and AR challenges and future directions.

The organization built on the experiences from the previous seminar "Virtual Realities 2008". The format of the seminar included sessions with standard presentations as well as parallel breakout sessions devoted to "hot-topics" in VR and AR research. It was the desire of the participants of the seminar that sufficient time for plenary discussion and working groups was scheduled. Before the seminar, the organizers solicited topics for the working groups. During the first days of the seminar these working groups were formed and a schedule was created. Plenary sessions were also scheduled to allow the working groups to report and discuss their findings.

Eight plenary sessions of presentations were scheduled throughout the week. Each session usually consisted of three 15 minute presentations followed by a 45 minute moderated discussion. Abstracts of the presentations are collected in the next chapter. The Monday afternoon plenary sessions were devoted to the topics of Telepresence and Human Embodiment. Tuesday morning the topics Applications and Health/Wellbeing were presented. Wednesday morning was devoted to a session on Virtual Environments. The Thursday morning sessions were on Commercial/Buisiness aspects of VR and Authoring/ Content. The last session was devoted to Augmented Reality.

Seven working groups were created and parallel breakout sessions held throughout the week. Each working group reported their findings in plenary sessions. The following lists the titles of the working groups:

- Real Time Interactive Systems – Architecture Issues
- VR Current State and Challenges
- 3D User Interfaces
- Avatars in Virtual Reality
- Scientific Visualization and VR
- Characterising Interactions in Virtual (and/or Real) Environments
- Unconventional Mixed Environments

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3 Overview of Talks

3.1 Human-subject experiments in Virtual Reality and 3DUI

Carlos Andujar (UPC – BarcelonaTech, ES)

This talk is about the major peculiarities and difficulties we encounter when trying to validate research results in fields such as virtual reality (VR) and 3D user interfaces (3DUI). We review the steps in the empirical method and discuss a number of challenges when conducting human-subject experiments. These challenges include the number of independent variables to control to get useful findings, the within-subjects or between-subjects dilemma, hard-to-collect data, experimenter effects, ethical issues, and the lack of background in the community for proper statistical analysis and interpretation of the results. We show that experiments involving human-subjects hinder the adoption of traditional experimental principles (comparison, repeatability, reproducibility, justification and explanation) and propose some ideas to improve the reliability of findings in VR and 3DUI disciplines.

3.2 "Live" will never be the same

Wolfgang Broll (TU Ilmenau, DE)

If you would just ask an arbitrary person on the street what she thinks VR is, she would probably answer: the matrix or maybe the Holodeck. Another possibility to express this would be to say: what would make a virtual environment undistinguishable from real life. There is no easy and no immediate answer to this question. However, if we look at AR, it seems that we are already much closer to a situation, where it becomes impossible or at least very difficult for an individual to distinguish between real and artificial (virtual) content. Recent works in the area of Diminished Reality and AR with real lighting reveal that the remaining steps in this area might be much smaller than usually estimated. Since adding live virtual content is already well established in the area of broadcasting and due to a rapidly growing market for virtual product placement, providing the necessary driving force, perfectly integrated sophisticated (live) virtual content will probably quite soon become a standard element within movies and broadcastings. Thus "live" transmissions will contain additional unreal content, while other real elements are discarded – not recognizable for the observer. Combined with recent advances in see-through display technologies we should not be surprised to already see individually adapted environments undistinguishable from (pure) reality within a couple of years. This seems feasible as in contrast to VR most of the content observed will still be real and virtual content can be adapted to the real one much easier than creating an entire convincible artificial world. As with the matrix and the Holodeck, this raises the question, how such a development will influence our daily life with respect to communication, interaction, and the reception of our environment.

3.3 A Multi-Projector CAVE with Gesture Recognition

Pere Brunet (UPC – BarcelonaTech, ES)

Joint work of Brunet, Pere; Andujar, Carlos; Vinacua, Alvar
Main reference The full paper is under review

In this talk, we present a novel four wall multi-projector CAVE architecture which is powered by 40 off-the-shelf projectors controlled by 12 PCs. It operates in passive stereo, providing high brightness at 2000 x 2000 pixel resolution on each of the 4 walls. We have achieved high resolution while significantly reducing the cost and increasing versatility: the system works with any mix of a wide range of projector models that can be substituted at any moment for more modern or cheaper ones. The uniformity of the final image is achieved using a specially designed self-calibration software which adapts each of the 40 projectors and guarantees concordance and continuity. The main contributions of our approach are: (a) The design and construction of a passive stereo, four-wall CAVE system with commodity hardware. It is based on 40 off-the-shelf DLP projectors and 12 PCs. The CAVE design achieves higher resolution and brightness while significantly reducing the total cost. (b) The system is versatile: it works with any mix of a wide range of projector models that can be substituted at any moment for more modern or cheaper ones. (c) Uniformity of the final image is guaranteed by a specially designed self-calibration software which adapts each of the 40 projectors and guarantees concordance and continuity. Independent self-calibration of the different CAVE walls is sufficient in most of the cases. And (d), A gesture-based, ergonomic interaction paradigm, based on dynamically merging the information from two orthogonal kinect sensors, has been designed and implemented. Interaction is intuitive and cableless.

3.4 Authoring VR in the Post-WIMP Age: Challenges, Approaches, Solutions

Ralf Doerner (Hochschule RheinMain – Wiesbaden, DE)

Joint work of Doerner, Ralf; Gerken, Katharina; Frechenhaeuser, Sven; Luderschmidt, Johannes
Main reference K. Gerken, S. Frechenhaeuser, R. Doerner, J. Luderschmidt, "Authoring Support for Post-WIMP Applications," in Proc. of the 14th IFIP TC 13 Int'l Conf. on Human-Computer Interaction (INTERACT'13), LNCS, Vol. 8119, pp. 744–761, Springer, 2013.
URL http://dx.doi.org/10.1007/978-3-642-40477-1_51

Currently, VR is heavily influenced by the advent of Post-WIMP user interfaces that outstrip the WIMP (Windows, Icons, Menus, Pointer) – paradigm of traditional PC user interfaces. Because of a larger user base, robust and reasonably priced hardware (e.g. mobile tablet PCs with multitouch screen, Microsoft Kinect, Leap Motion, Google Glasses) becomes available that can be readily used in novel VR setups with an increasing number of sensors. Users become acquainted with more "exotic' input and output methods facilitating novel interaction designs. VR setups can be put in more contexts (e.g. living spaces) where users "own" parts of the VR setup. This allows for novel application areas (e.g. ambient intelligence), more complex VR content (e.g. virtual humans with sophisticated behavior) and introduces new authoring groups to VR (especially authors with non-technical background such as designers, domain experts or end users). One major limiting factor for exploiting this new potential for VR is the problem that authoring processes are often not suited for new author groups and not able to deal with its complexity, requiring hand-crafted solutions which are costly to produce and to adapt. Several approaches to tackle problems associated with authoring aspects will be presented in the talk. First, novel authoring tools based on the Post-WIMP paradigm are introduced. Second, authoring processes relying on components and meta data are put forward. Third, the application of Self-X methodologies (e.g. Self-Organization or Self-Adaptation) to the field of VR is examined (e.g. creators of VR systems can be freed from tasks such as manual integration of additional sensors in a VR system and calibration if this can be performed automatically using Self-Configuration). Fourth, complex event processing (and according languages such as Esper) can be employed to provide VR application developers with more abstract events allowing for easy handling of large volumes of sensor data. The discussion of these approaches will cover ideas, solutions and visions for VR authoring. Also the question what VR can contribute to Post-WIMP paradigms will be addressed. The provision of suitable methodologies for authoring VR systems and creating VR content is a crucial issue for the success of VR since it determines key characteristics of VR applications such as quality, usability, applicability, flexibility and cost efficiency.

3.5 Three Topics in Designing Augmented Reality

Steven K. Feiner (Columbia University, US)

Joint work of Feiner, Steven K.; Dedual, Nick; Henderson, Steve; Oda, Ohan; Sukan, Mengu; Tversky, Barbara

As Augmented Reality (AR) technologies stand poised to become a part of our daily lives, how can we design effective user interfaces that incorporate them? I will provide brief overviews of research being done by Columbia's Computer Graphics and User Interfaces Lab on three topics:

- How can we use AR to assist users in training for and performing tasks, alone and in collaboration with others? What can we do to avoid providing too much information, while helping users understand the task well enough that they can be effective even if the AR technology were to fail.
- What is the place in AR for points of view other than the immediate first- person?
- How can we combine multiple heterogeneous displays in AR, to benefit from their complementary advantages?

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3.6 Local and Remote Collaboration in Multi-User Virtual Reality

Bernd Froehlich (Bauhaus-Universität Weimar, DE)

Joint work of Beck, Stephan; Kunert, André; Kulik, Alexander; Froehlich, Bernd
Main reference S. Beck, A. Kunert, A. Kulik, B. Froehlich, "Immersive Group-to-Group Telepresence," IEEE Trans. on Visualization and Computer Graphics, 19(4):616–25, March 2013 (Proceedings of IEEE Virtual Reality 2013, Orlando, Florida).
URL http://dx.doi.org/10.1109/TVCG.2013.33

Our immersive telepresence system [1] allows distributed groups of users to meet in a shared virtual 3D world. Our approach is based on two coupled projection-based multi-user setups, each providing multiple users with perspectively correct stereoscopic images [3]. At each site the users and their local interaction space are continuously captured using a cluster of registered depth and color cameras. The captured 3D information is transferred to the respective other location, where the remote participants are virtually reconstructed. Local and remote users can jointly or independently explore virtual environments and virtually meet face-to-face for discussions. We structure collaborative activities of collocated and remote users using Photoportals [2]. Virtual photos and videos serve as three-dimensional references to objects, places, moments in time and activities of users. They can be shared among users and serve as portals to the captured information. Our Photoportals also provide access to intermediate or alternative versions of a scenario and allow the review of recorded task sequences that include life-size representations of the captured users.

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3.7 Telepresence Systems: What Is To Be Done

Henry Fuchs (University of North Carolina at Chapel Hill, US)

Joint work of Maimone, Andrew; Yang, Xubo; Dierk, Nate; State, Andrei; Dou, Mingsong; Fuchs, Henry
Main reference A. Maimone, X. Yang, N. Dierk, A. State, M. Dou, H. Fuchs, "General-Purpose Telepresence with Head-Worn Optical See-Through Displays and Projector-Based Lighting," in Proc. of 2013 IEEE Virtual Reality (VR'13), pp. 23–26, IEEE, 2013.
URL http://dx.doi.org/10.1109/VR.2013.6549352
URL http://www.cs.unc.edu/ maimone/media/GeneralTelepresence_VR_2013.pdf

We have known for decades what is needed for an effective telepresence system: 3D acquisition of the remote scene, and 3D display of the remote scene to the local participant. For flexibility, the display of the remote scene should be an augmentation of the local participant's view of his or her local surroundings. Variations of telepresence systems often appear in science fiction films and more recently in television, even in news programs. All of these appearances to date are achieved by special effects of some sort, since the technology to achieve telepresence is still inadequate for actual use. The widespread availability of two different technology trends in the past few years have accelerated research interest in telepresence: 1) inexpensive depth cameras, most notably Microsoft Kinect, and 2) small high-resolution displays for mobile devices, from which head-worn displays can be built. Significant challenges still remain, however. For a useful telepresence system, a scene capture using multiple depth cameras is likely necessary. Unfortunately, the active (infra-red) light-based technology in Kinect depth cameras degrades significantly, due to interference, when multiple units are used in the same scene. The other part of the system, the display, is also still a challenge. Augmented visualization displayed within the local user's surroundings still cannot be achieved effectively. Such augmented visualization is desirably since in many, perhaps most situations, there are other local participants or local objects, with which the local participant wants to interact while interacting with the remote participant(s). To produce a proper combined augmented, mixed visualization, the system has to perform proper occlusion in 3D: the remote participant(s) have to occlude local objects behind them and they have to be occluded by local objects in front of them. Thus 3D scene acquisition is likely necessary for both local and remote spaces. In addition, some kind of optical or video see-through head-worn display may be needed for each of the participants. Current versions of such displays with occlusion capabilities are either very bulky or have narrow field of view. Until adequate such displays are developed, other alternatives may be more attractive: 1) large-format multi-viewer autostereo displays, and 2) simple optical see-through head-worn displays coupled with local light control accomplished with projector-based illumination. The availability of head-worn displays such as Google Glass and Lumus DK-32 will accelerate interest in and work on head-worn displays, which will eventually benefit telepresence applications and systems.

3.8 AR UI: Balancing Real and Virtual

Raphael Grasset (TU Graz, AT)

Augmented Reality has moved from lab environments to the hands of the general public over the last few years. Yet, designing Augmented Reality user interfaces (AR UI) for the next generation of AR applications remains a general issue. Current commercial AR user interfaces mimics virtual reality or traditional user interface (e.g. touch screen) rather than fully capturing the essence of AR: Real and Virtual.

In this talk I give an overview of the limitations of current AR user interfaces and a list of case studies, based on my previous work ([4], [3], [1], [2]), on how we can better balance real and virtual in the design of AR UI. I describe how a seamless AR world can rely on better view management techniques, methods for creating virtual content out of real artefacts, and the effective combination of computer vision, computer graphics and HCI. Finally, I outline a research agenda and new principles for the development of future generation of AR UI: leveraging visual perception theories and methods, more adaptive and contextual UI, new development tools for UI design (simulator, datasets) and an AR Semiotics framework.

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3.9 AR and VR Everywhere?

Tobias Hoellerer (University of California – Santa Barbara, US)

AR and VR hold enormous promises as paradigm-shifting ubiquitous technologies. We all have seen indications of this potential, but clearly most of us are still far from using AR or VR on a regular basis, everywhere. What will it take to get closer to mass adoption? My presentation discussed existing success stories and ongoing limitations of AR and VR technologies on the roadmap to seamless interaction with the physical world. New developments in sensors and real-time computer vision, coupled with near-to-universal connectivity may make it possible to finally scale the user interface experience from small screens to the wider context of the world before us. And on the way there, somebody will surely want your data...

3.10 Applications of Avatar Mediated Interaction to Teaching, Wellness & Education

Charles E. Hughes (University of Central Florida – Orlando, US)

Joint work of Hughes, Charles E.; Dieker, Lisa; Hynes, Michael; Nagendran, Arjun; Welch, Gregory

Teacher education usually involves practice with real children either as their sole teacher or in an apprentice role. This puts children (and teachers) at risk while skills, especially soft skills associated with human-to-human interaction, are still being learned. Virtual environments provide an opportunity for teachers to practice skills without interfering with the education of children and without placing themselves at the mercy of these same children while their classroom management, pedagogy and even content skills are still developing. Unfortunately, purely virtual worlds (ones driven by programmed behaviors) are not adaptive enough to provide realistic responses to verbal and non-verbal interactions, and are not capable of handling the almost random directions that the conversations may or should take. Similarly, virtual worlds that deal with protective strategies, e.g., for pre-teens facing enormous peer pressure, and those that deal with counselling situations, need to reflect the subtleties of human interaction that are not presently attainable through programmed behaviors, even those encompassing evolutionary changes in those behaviors.

The presentation focused on how a human-in-the-loop controlling the virtual avatars can provide the realism needed to address the areas mentioned above, as well as other applications involving intense human-to-human verbal and non- verbal interaction. Specifically, the talk focused on TeachLivE (Teach and Learning in a Virtual Environment), a system in current use at 32 universities and several school districts in the U.S. The TeachLivE system provides in-service and pre- service teachers the opportunity to practice skills and reflect on their own performances. The reflection component is achieved through an integrated after- action review system that support real-time and off-line tagging of events, along with the use of these tags to select video sequences that demonstrate the teacher's skills (or lack thereof) in different contexts. The system's scalability is enhanced by its micropose-based network protocol and its use of just one human inhabitor to control multiple avatars.

In addition to the applications already mentioned, the presentation discussed the uses of avatar-mediated interaction for children and young adults with autism and the employment of the underlying virtual settings in free-choice education.

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3.11 VELOS – A VR environment for ship applications: current status and planned extensions

Panagiotis D. Kaklis (National Technical University of Athens, GR)

VELOS (Virtual Environment for Life On Ships) is a multi-user VR system enabling passenger- and crew-activities for normal/hectic conditions. Ship evacuation currently constitutes its main application area. In the future we plan to extend its coverage with crew-ergonomics and -training as well as passenger comfortability. VELOS is based on VRsystem, a generic multi-user environment that adopts a client-server architecture and offers a variety of functionality including: geometric, topological and VR modeling, crowd-microscopic modeling, interfacing to simulation packages (so far: seakeeping behavior, fire evolution) and networking support.

In this presentation we focused on two higher-order steering behaviors, namely "passenger grouping" and "crew assistance", that we have recently embedded in VELOS by combining and/or enriching standard steering behaviors already available in VELOS. The performance of these behaviors has been illustrated through two tests. The first test was a generic one, involving the moving of 70 persons through a simple four-room configuration. The second test was associated with the evacuation of a ro-ro passenger ship, involving the movement of 100 passengers from their cabins in the after-zone of Deck 5 to the corresponding muster station on Deck 7. The recorded outcomes for both tests indicate that VELOS is capable for materializing complex evacuation scenarios for evaluating/modifying exiting general-arrangement layouts as well as crew training in immersive environments.

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3.12 VR Interfaces and Animation Algorithms for Modeling Autonomous Demonstrators

Marcelo Kallmann (University of California – Merced, US)

Joint work of Kallmann, Marcelo; Camporesi, Carlo; Mahmudi, Mentar; Huang, Yazhou
URL http://graphics.ucmerced.edu/index.html

This talk addresses the approach of developing animation algorithms and VR interfaces that are suitable for modeling motions to be used by autonomous demonstrators. VR interfaces allowing users to build motion clusters designed for inverse blending are presented, and planning methods on blending spaces are introduced for achieving humanlike variations that address obstacle avoidance for generic actions. The approach is complemented with locomotion synthesis in order to well position the virtual character for execution of given upper-body actions. As a result, autonomous virtual characters are able to plan and execute motions that are similar to demonstrated examples and that address new constraints and parameterizations.

3.13 Interactive Content for Well-being

Yoshifumi Kitamura (Tohoku University, JP)

Well-being is a concept which is used for a comprehensive understanding of subjective well-being, life satisfaction, positive emotion/affect, and so on, in positive psychology. Although it is difficult to achieve the well-being directly using the information technologies, I would like to conduct and accumulate my small pieces of effort toward the well-being by the research of interactive content. For this purpose, I have just started a research project to make a space of interpersonal interaction more active, enjoyable, efficient, comfortable, ... by research on interactive content. I introduced three research examples:

1. Understanding the "atmosphere" by verbal/nonverbal behaviors of persons measured by sensors,
2. D-FLIP: Dynamic & Flexible Interactive PhotoShow
3. TransformTable: A Self-Actuated Shape-Changing Digital Table

3.14 AR boundaries: human-factor implications of pro-longed HWD usage

Ernst Kruijff (Hochschule Bonn-Rhein-Sieg, DE)

Main reference E. Kruijff, J.E. Swan II, S. Feiner, "Perceptual issues in augmented reality revisited," in Proc. of the 9th IEEE Int'l Symp. on Mixed and Augmented Reality (ISMAR'10), pp. 3–12, IEEE, 2010.
URL http://dx.doi.org/10.1109/ISMAR.2010.5643530

Augmented reality (AR) is a field of research that has seen an incline in attention over the last years, driven foremost by simple cell phone applications. Nonetheless, the field of research itself has steadily been growing over well over a decade. Predominantly, the focus has been on improving technical aspects of Augmented Reality, such as handling tracking or improving computing at small-scale platforms. As an effect of these efforts, systems have evolved from bulky installations towards powerful wearable platforms.

However, whereas AR itself is highly concerned with vision aspects, relatively little work has been performed on perception or cognition. As a result, many AR systems are suffering from the effects caused by problems such as depth distortion, focal attention switching, incorrect creation of object relationships, low legibility and occlusion. These issues limit the usability of AR applications considerably, in particular those systems that are based on so-called optical see- through systems. At the same time, both researchers and industry are in need of background information or even guidelines that may drive in particular applications that will be used by users in a pro-longed way. However, pro-longed usage is badly understood and may even further stress particular issues that already limit occasionally used applications. The presentation introduced several issues that merit further research, including visual tunneling, training effects, the usage of multiple perspectives (perceptual issues), and the effects on the user's cognitive map, search behavior, cognitive load, and mood alteration (cognitive or cognition- related issues). It is concluded that understanding long-term effects is important for sustaining interest in AR by both research and industry, as well as the actual end-users. To drive this understanding it will be necessary to lay out a structural approach to subsequently study and classify issues and effects.

3.15 Brain-Computer Interfaces and Virtual Environments

Anatole L"ecuyer (Inria, Rennes, FR)

Brain-Computer Interfaces (BCI) are introducing a novel user input for interaction with Virtual Environments: the user mental activity or cognitive processes. This input can be used in different ways, either for a direct control of virtual environments with "mental commands", or in an implicit interaction scheme by monitoring the cerebral activity and adapting the interaction or the content of the VE to the user "state of mind". Impressive prototypes exist today that combine immersive virtual reality technologies and BCI. But a lot a difficult scientific challenges remain for making this a robust and effective solution, involving multi-disciplinary research in Neuroscience and Neurophysiology, Signal-Processing, Human-Computer Interaction and Virtual Reality. But we believe we should see in the future promising simulators based on BCI and VR for industrial or medical training, rehabilitation and reeducation, or entertainment and videogames.

3.16 Lessons learned from introducing VR/AR in the German maritime industry

Uwe Freiherr von Lukas (FhG IGD, Rostock, DE)

In my presentation I shared several experiences we made at Fraunhofer IGD when introducing VR and AR to several areas of the maritime industry. There are many chances to use advanced visualization and interaction in the different stages of the lifecycle of a ship from design our production to training, operation and retrofit.

Due to the specific requirements of the maritime industry (one of a kind product, large data volume, projects under extreme time pressure) available standard VR solutions of other industries cannot be used off the shelf. So we recommend a use case-driven approach that leads to tailor-made solutions in terms of data integration, hardware setup, interaction and functionality. However, the efficiency in implementing those solutions and the return on investment of applying VR/AR in this way is still an open question.

3.17 Is there a significant market for industrial Virtual Reality today or tomorrow?

Uwe Freiherr von Lukas (FhG IGD, Rostock, DE)

The talk is mainly based on a study that characterizes and forecasts the German market for industrial 3D applications. It shows, that the market is dominated by small and medium-sized companies and that there are more service provider than hard- or software companies. The study states a market growth between 3% and 15% – depending on the penetration of 3D in new industrial processes. This growth is based on 3D technology spreading in various industries and processes. Classical VR does not have a significant share of the cake. This can be explained by the enormous complexity that VR systems still have and the necessity for well-trained staff to operate such an installation.

3.18 Perception & Action in Virtual Environments

Betty Mohler (MPI für biologische Kybernetik – Tübingen, DE)

URL http://www.youtube.com/user/MPIVideosProject

In the Perception and Action in Virtual Environments research group, our aim is to investigate human behavior, perception and cognition using ecologically valid and immersive virtual environments. Virtual reality (VR) equipment enables our scientists to provide sensory stimulus in a controlled virtual world and to manipulate or alter sensory input that would not be possible in the real world. More specifically, VR technology enables us to specifically manipulate the visual body, the contents of the virtual world, and the sensory stimulus (visual, vestibular, kinesthetic, tactile, and auditory) while performing or viewing an action. Our group focuses on several different areas, all areas involve measuring human performance in complex everyday tasks, i.e. spatial judgments, walking, driving, communicating and spatial navigation. We investigate the impact of having an animated self-avatar on spatial perception, the feeling of embodiment or agency, and on the ability for two people to effectively communicate. Our goal is to use state-of-the-art virtual reality technology to better understand how humans perceive sensory information and act in the surrounding world. We use HMDs, large screen displays, motion simulators and sophisticated treadmills in combination with real-time rendering and control software and tools in order to immerse our participants in a virtual world. In this talk I will show videos of our technical setups and explain how I became interested in spatial perception in virtual reality. See specifically the following videos which are available on-line: http://www.youtube.com/user/MPIVideosProject.

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3.19 Human Body/Embodiment and Related Perceptions

Tabitha C. Peck (Duke University, US)

Joint work of Peck, Tabitha C.; Seinfeld, S; Aglioti, M; Slater, M
Main reference T.C. Peck, S. Seinfeld, S.M. Aglioti, M. Slater, "Putting Yourself in the Skin of a Black Avatar Reduces Implicit Racial Bias," Consciousness and Cognition, Vol. 22, Issue 3, pp. 779–787, September 2013.
URL http://dx.doi.org/10.1016/j.concog.2013.04.016

In this talk I present previous work that shows that it is possible to generate in people the illusory sense of ownership of a virtual body in immersive virtual reality. This can be achieved through synchronous multisensory stimulation with respect to the real and virtual body. However, the consequences of such embodiment have not been explored, for example, would embodiment of someone with racial bias in a body of the other racial group diminish their bias? Previous research suggested that physically embodying people in racially-different avatars decreased empathy and increased implicit racial bias. In this talk, I present results that demonstrate that embodiment in differently-raced avatars is possible and that embodying Caucasian participants in dark-skinned avatars for only ten minutes can significantly reduced implicit racial bias compared to embodying participants in light-skinned avatars. The results suggest that virtual environments and virtual embodiment seem promising for allowing the possibility to change socially negative attitudes and behaviour.

3.20 White Paper on Haptics

Jerome Perret (Haption – Aachen, DE)

Main reference Haptic-SIG, "White Paper on Haptics as a Contribution to the Horizon 2020 Framework Program," EUROVR, 2012.
URL http://www.hapticsig.org/sites/default/files/White%20paper%20on%20Haptics-final.pdf

In this talk, we outline the main scientific and technological challenges identified in the White Paper published by the Special Interest Group (SIG) on Haptics of the EuroVR Association. We focus on three main topics: haptic rendering, haptic technology, and standarization. In the domain of haptic rendering, further research is needed in order to enable the physical simulation of very large scenes including complex deformable objects, while keeping a high-frequency framerate. Regarding haptic technology, besides the growing demand for haptic/tactile feedback on mobile terminals, further effort should be invested in the development of low-cost and universal devices (including Open Source hardware), and software for haptic collaboration on networks. Standardization, supported by Open Source software libraries and middleware, will ensure that R&D efforts benefit all users.

3.21 VR for Disabled Persons: Current Research and Future Challenges

John Quarles (University of Texas at San Antonio, US)

Joint work of Quarles, John; Guo, Rongkai; Samaweera, Gayani
Main reference G. Samaraweera, R. Guo, J. Quarles, "Latency and Avatars in Virtual Environments and the Effects on Gait for persons with Mobility Impairments," in Proc. of the IEEE Symp. on 3D User Interfaces (3DUI'13), pp. 23–30, IEEE, 2013.
URL http://dx.doi.org/10.1109/3DUI.2013.6550192

The objective of this talk is to give insight into how to design effective virtual environments for disabled persons. Current knowledge of how disabled persons experience virtual reality is largely based upon virtual rehabilitation literature, which is very application specific. Moreover, almost all prior basic research has been performed with healthy participants. Thus, there is a significant need for basic, generalizable research results that evaluate disabled persons interaction and experience in virtual environments. This talk presents the latest research toward this goal, specifically summarizing findings of how disabled persons respond to latency, avatars, and other immersive stimuli can affect presence and interaction in virtual environments. Future challenges are discussed and future work is proposed. Ultimately, there is a need for much more basic research on how disabled people experience virtual reality.

3.22 Taking Augmented Reality out of the Laboratory and into the Real World

Christian Sandor (University of South Australia, AU)

URL http://www.magicvisionlab.com/

This presentation introduces our efforts to create commercial applications with Augmented Reality (AR), a user interface technology that overlays computer graphics over the user's view of their surroundings. Together with our industry partners, we investigate two scenarios: first, to mobile information browsing on mobile phones (Nokia); second, to industrial product design (Canon).

During the last decade, mobile information browsing on mobile phones has become a widely-adopted practice. This was made possible by the increase of wireless networking infrastructure and the ever increasing amount of online data. By employing AR, we enable users to access digital data much more fluidly and therefore assist everyday tasks much more effectively than with previous user interfaces. An example is AR X-Ray vision, which enables users to look through buildings and other obstacles.

A common task in industrial product design is to create physical prototypes of new products. A common prototyping method is to use 3D printers to create physical models. However, 3D printers are slow and expensive and changes to the shape are costly and labour intensive. We are investigating completely virtual prototypes that can be seen through AR and touched through a haptic device. This enables users to interactively change the shape and appearance of a prototype. After having successfully demonstrated virtual prototypes using a pen-shaped haptic device, we are currently developing a system that enables users to touch the virtual prototypes with all their fingertips.

Videos of our prototypes can be viewed at: http://www.magicvisionlab.com.

3.23 Augmented Reality Visualization Pipeline

Dieter Schmalstieg (TU Graz, AT)

Augmented Reality (AR) is a new medium and is primarily used for presenting visual information. Like with desktop computing, visualization techniques are needed to make sure human users understand the information presented in AR. However, principles of visualization are hardly applied in AR. This talk proposes to adapt a standard visualization pipeline for the needs of AR and organize the presentation of visual information in AR around the concepts of data transformation, filtering and rendering.

3.24 Augmented Reality in Altered Gravity

Oliver Staadt (Universität Rostock, DE)

Joint work of Markov-Vetter, Daniela; Mittag, Uwe; Staadt, Oliver
Main reference D. Markov-Vetter, E. Moll, O. Staadt, "Evaluation of 3D selection tasks in parabolic flight conditions: pointing task in augmented reality user interfaces," in Proc. of the 11th ACM SIGGRAPH Int'l Conf. on Virtual-Reality Continuum and its Applications in Industry (VRCAI'12), pp. 287–294, ACM, 2012.
URL http://dx.doi.org/10.1145/2407516.2407583

Intra-vehicular control and experiment support in manned spacecraft, such as the ISS, can benefit from Augmented Reality systems. To understand AR interaction under micro- and hyper-gravity conditions, we conducted a series of experiments during the 56th and 58th ESA Parabolic Flight Campaigns. We measured user performance for aimed pointing tasks during different phases of a parabolic flight: (i) normal gravity (1-g), (ii) zero gravity (0-g), and (iii) hyper gravity (1.8-g). In addition to pointing accuracy and speed, we obtained biofeedback of subjects through heart-rate variability (HRV) measurements.

We believe that the results of our experiments will influence the design of future Augmented Reality systems in altered-gravity environments.

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3.25 The Role of the Body in Perceiving Real and Virtual Spaces

Jeanine Stefanucci; Michael Geuss; Kyle Gagnon; Sarah Creem-Regehr

Our work investigates the perception of the body and space in real and virtual environments with the aim of determining whether observers view virtual environments as intended by designers. Using measures adopted from embodied perception theories in psychology, which emphasize the role of the body in space perception, we test whether observers perceive virtual spaces akin to real spaces in the context of body capabilities for action. In immersive virtual environments (IVEs) and real environments, we changed either the physical (real world) or virtual body to assess its influence on whether or not people said they could pass through or under an aperture. IVEs allowed for body manipulations that were not possible in the real world. We found that when the body was made wider or taller through physical manipulations in the real world, people's estimates of passing through or under an aperture were altered along with their judgments of the width or height of the aperture. We also found that judgments of the ability to pass under or through an aperture were similar across real and virtual environments even when no changes to the body were implemented. Finally, we showed that virtual manipulations of body dimensions (some not possible in the real world) affected decisions about action with respect to apertures in IVEs. Overall, the findings suggest that the body plays a role in space perception in both real and virtual environments, suggesting that care should be taken when constructing virtual representations of the body, especially in the case of self avatars.

3.26 Telexistence

Susumu Tachi (Kaio University, JP)

Main reference S. Tachi, "Telexistence," World Scientific, ISBN-13 978-981-283-633-5, 2010.
URL http://tachilab.org/modules/publications/

3.26.1 What is Telexistence

Telexistence is a fundamental concept that refers to the general technology that allows a human being to experience a real-time sensation of being in a place other than his/her actual location and to interact with the remote environment, which may be real, virtual, or a combination of both [1]. It also refers to an advanced type of teleoperation system that allows an operator at the controls to perform remote tasks dexterously with the feeling of being in a surrogate robot working in a remote environment. Telexistence in the real environment through a virtual environment is also possible. Sutherland [2] proposed the first head-mounted display system, which led to the birth of virtual reality in the late 1980s. This was the same concept as telexistence in computer-generated virtual environments. However, it did not include the concept of telexistence in real remote environments. The concept of providing an operator with a natural sensation of existence in order to facilitate dexterous remote robotic manipulation tasks was called "telepresence" by Minsky [3] and "telexistence" by Tachi [4]. Telepresence and telexistence are very similar concepts proposed independently in the USA and in Japan, respectively. However, telepresence does not include telexistence in virtual environments or telexistence in a real environment through a virtual environment.

In this talk an overview is given of the telexistence manipulation system TELESAR up to version TELESAR V.

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3.27 Embodiment via Physical-Virtual Avatars

Gregory F. Welch (University of Central Florida – Orlando, US)

Joint work of Welch, Gregory F.; Hughes, Charles E.; Nagendran, Arjun; Bailenson, Jeremy N.; Slater, Mel

We have developed and demonstrated a general-purpose human surrogate system we call a Physical-Virtual Avatar (PVA). We can capture 2D imagery, head/facial motion, and audio of a moving, talking real human inhabiter, and reproduce those signals on the PVA, delivering a dynamic, real-time representation of the user to multiple viewers; while simultaneously presenting the inhabiter with dynamic imagery and audio of the remote participants and environment. Compared to conventional televideo or telepresence technologies we believe such a PVA system could be more useful in one-to-one or small group social situations where voice, eye gaze, facial expressions, body movement (kinesics), and in particular mobility and the use of space (proxemics) are more likely to affect the thoughts, feelings, and behaviors of the humans involved.

We are planning research and development aimed at improving our PVA methods and prototype systems, and using those systems to explore behaviors and beliefs about the remote existence of the human inhabiters. With our education and medical collaborators, we are planning to explore the use of PVAs to improve the quality of student access to peers and experts, and the quality of life for those with mobility restrictions such as hospital/home-bound individuals.

Our objectives include developing the graphical/visual, aural, computational, and system affordances of the PVA necessary (a) to create the illusion for an inhabiter that they are at a remote location, and (b) for remote participants that the inhabiter is with them; exploring the thoughts, feelings, and behaviors of the humans involved in PVA-mediated social interaction, and how they are influenced by the perceived presence of their counterparts; investigating the potential impact in application-driven scenarios involving education (e.g., cooperative learning and same age peer tutoring) and well-being (e.g., the psychological "escape" of humans confined to home or hospital); and fostering a community of researchers engaged in avatars and related social psychology.

4 Working Groups

4.1 Realtime Interactive Systems – Architecture Issues

Roland Blach (FhG IAO, Stuttgart, DE)

Realtime Interactive Systems (RIS) are an increasingly important field of research. Application areas range from Virtual, Mixed, and Augmented Reality (VR, MR, and AR) to advanced Human-Computer Interaction (HCI), realtime simulation, and computer games. Several RIS aspects are equally relevant to ambient and pervasive computing as well as to robotics. All these fields differ in many aspects, from concepts to method sets, and hence have their own research communities. But they additionally exhibit a very interesting and important intersection area when it comes to the software engineering parts and principles involved. The challenge of RIS systems-engineering lies in the contradictory coupling requirements:

tight coupling of system and user to maximize experience/immersion vs. loose coupling of components to master complexity.

Based on a proposal for the classification of RIS rooted in the VR/AR/MR domain – a RIS architecture questionnaire to capture individual system characteristics – the intention of the discussion was to get closer to an understanding of how to analyze and compare RIS from an architectural point of view instead of a feature based view. The proposed questionnaire was considered too large and the meaning of the questions is too fuzzy. Besides the questionnaire a thorough requirement analysis could be carried out but is probably too broad as the application domains of RIS are too heterogeneous. Another approach could be the analysis of 3-5 very different systems. Open questions are then: a) which criteria and b) which systems.

To give advice to system architects, another option could be to gather structured knowledge of adjacent domains as e.g. operating systems, X11, HTML5 or transactional memory.

Two contradicting trends for the generalization of RIS have been discussed. Many interaction researchers seem to be happy with commercially available systems which provide good development support and lively communities. This could lead to a defacto standard which also supports interoperability. Nevertheless it is important that these systems provide enough information of their internal behavior and timing that user studies can be interpreted meaningfully. On the other hand interaction researchers who work in areas where fast render times and low latency is necessary do not believe in general engines but want detailed control of the algorithms. This often leads to individual and heavily customized systems e.g. in case of tight coupling renderer and interaction. Also different graphical data necessitates other interaction paradigms which could possibly not be provided by standard system architectures.

All discussed points have added new information or confirmed existing knowledge to the state of the art, but no final conclusions can be drawn. The discussion will continue and the remarks and result of the breakout session will be fed back to the SEARIS (Software Engineering and Architectures for Realtime Interactive Systems) community and discussed further on the annual workshops. We hope that these discussions might improve the understanding of system patterns and consequently will lead to a more deliberate if not better system design. The discussion should be understood as a starting point for further discussions which the participants would be happy to continue.

4.2 VR Current State and Challenges

Carolina Cruz-Neira (University of Louisiana at Lafayette, US)

The members of this group were a well balanced variety of pioneers, expert researchers, industry practitioners, and young investigators. The conversation was guided by a series of discussion questions that were answered or, in some cases, debated, among the group's members. The group started the discussion answering the questions of what VR is today and what we think is still (if anything) exciting about VR. The consensus was that VR has become more pervasive and has infiltrated other fields, and therefore is not a "one size fits all" definition. The main excitement of VR is still the potential to provide experiences like no other technology and with the advances on the underlying technologies, the experiences are becoming increasingly more compelling and with higher fidelity. The group also discussed the current barriers that are preventing a wider acceptance of VR and agreed that the most challenging issue was the lack of a common infrastructure to provide homogeneity across platforms, interactive devices and applications. The discussion continued with reviewing the current markets for VR, many of them already outside research labs and an overview of success stories. The discussion then evolved towards the challenges still left to address and the potential new opportunities that will be opened and enabled by addressing those challenges. The discussion wrapped up with the enthusiastic conclusion that VR is an exciting field, still very relevant, and still a great deal of fascinating challenges to solve.

4.3 3D User Interfaces

Rob Lindemann (Worcester, Massachusetts, US)

Since the previous Virtual Realities seminar (08231) at Dagstuhl in June 2008, there has been powerful movement towards a Democratization of 3D User Interaction, driven mainly by the reduction in cost of motion-sensing equipment, the wide-spread use of powerful mobile devices, and renewed interest by the general public in virtual reality through games.

The introduction of the Microsft Kinect in 2010 helped feed general interest in motion sensing for games started by the Nintendo Wii controller in 2006. Participants in the breakout session viewed this development as significant for both technical and social reasons. It created an intense sub-culture of "citizen researchers" who began experimenting with the technology, devising interesting and novel ways of using depth-camera input. Unbeknownst to these new 3DUI developers, many of the difficulties encountered in their works had been highlighted during the work of our community over the past two decades of 3DUI research. Despite this general lack of building on previous research, we felt it was positive that many new minds had been exposed to 3DUI development in general.

The global adoption of mobile devices, mainly iOS and Android, has created new interaction scenarios for on-the-go users. Mobile devices today typically provide several novel ways for users to interact with them, including accelerometers, gyroscopes, GPS, multi-touch surfaces, high-resolution displays, proximity sensors, voice input, and high-bandwidth connectivity. Social network usage has also led to new actions common across multiple applications, such as sharing, "liking," and location-based services, such as recommender systems and mapping. In addition, the use of Augmented Reality (AR) techniques has also seen increased interest in mobile settings, giving rise to new user interaction research problems to work on.

Many of the new interface devices have been born from a resurgence in video gaming, though wide-spread use of novel interface devices still seems elusive. Like the Wii before it, many players who were so excited to "get off the couch" to play in new and interesting ways have returned to their sedentary play styles; The hype around new devices seems to fade once players understand how much effort it takes to play. We feel this helps to highlight the need for continued, careful research in the field of 3DUI.

We also discussed what interesting research areas have appeared recently. One important one was a re-evaluation of the list of common tasks performed in immersive environments forwarded by Bowman et al. [1], in their seminal book on the topic. While there was widespread agreement that the common list of tasks, namely, Selection, Manipulation, Navigation, Symbolic Input, and System Control, has served us well, some modifications should be proposed. It was felt (and supported by Ernst Kruijff, who was present at the session) that the System Control area was somewhat of a "grab bag" of things that didn't fit neatly into the other areas, and could be re-explored. In addition, there was some support for combining Selection and Manipulation into a single area, as it is often the case that users use them together in a single action, and separating them does not address the need to make the techniques used in a given system complimentary. This brings up another common feeling of the group, that there is still little work on selecting solutions for each of the tasks that work well together, and that reduce cognitive and technical load of switching between them. For example, a user might need to navigate to a particular location in the world, manipulate some aspect of the world at that location, then move to another location, etc. More work needs to be done on transitioning between these tasks.

The group also felt that Avatar Control should be added to the list of common tasks, given the prevalence of low-cost technical methods for capturing user posture, and the need to convey that information to other immersed users. Another possible task that was viewed as becoming more important going forward, particularly in the mobile domain, was Information Search. Given how much users today rely on accessing information from the Internet, the varied sources for this information, and the wide range of types of data (e.g., images, video, social network feeds, etc.), finding ways of searching efficiently in immersive worlds is an open, interesting, and relatively unexplored problem.

In sum, this was a very productive breakout session. It became clear that research in 3DUI continues to be a hot field due to the growing number of users, usage scenarios, and low-cost equipment entering the market. Also, some future areas of focus emerged, leading to excitement for continuing to move the field of 3DUI forward.

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4.4 Avatars in Virtual Reality

Betty Mohler (MPI für biologische Kybernetik – Tübingen, DE)

Avatars are an increasingly popular research topic in the field of virtual reality. The first 20-30 minutes of our discussion was spent discussing exactly what participants meant by "Avatars" and it was clear that our definitions and needs for virtual humans fell into several categories. Avatars are often defined as digital models of people that either look or behave like the users they represent (see [1]). However, other terms like virtual humans (virtual characters that try to represent a human as close in fidelity as possible) or social agents (virtual characters that fulfill a certain purpose through artificial intelligence) are also often referred to as avatars. Avatars can be achieved in multiple ways, i.e. video based capture[3], pre-made avatars experienced as the user's own body due to first-person perspective and visual-motor or visual-tactile stimulation (i.e. in [2]) and physical projections of video captured data[4]. These are just a few of the many manifestations of avatars in virtual reality.

In order to achieve high-fidelity virtual agents that act in a human way many problems need to be solved by a multi-disciplinary research group. Virtual social agents must be able to move like humans, have casual conversation, appear intelligent, be interactive, be both reactive and proactive (specific to the user), be empathetic, perform certain functions, follow basic rules of proxemics, receive and give sensory feedback (visual, tactile, auditory). Some of the most promising applications for avatars and social agents in virtual reality are: telepresence, ergonomics/simulation, training, teaching and education, medical and health, basic science (understanding human behavior, see [5]), and of course gaming and entertainment.

In this discussion time we had three breakout groups where we tried to define grand challenge examples for avatar research. One group discussed the challenges involved with the ability to remotely care for an elderly parent or remotely put your child to bed (as a second parent). These challenges involve communicating face to face, physical interaction (to comfort/support, to help with household tasks), observe monitor mental and physical health signs, the believable presence of the remote parent to a child (visual, voice, size) and the ability to embody a remote avatar. Another group discussed a scenario for avatars in the medical health profession and education of medical professionals, specifically where limited discourse is occurring. Important to these scenarios are the ability to build trust, convey empathy and have confidence in the sometimes uncertain or emotional information that is being shared. Finally, another group considered the challenge of being able to have a portable self-representation which could be brought into the virtual reality application you are using. The challenges here are system challenges of having a standard for virtual reality with regard to model, animation method and ethical issues with regard to data security. Specifically this group considered how the data for individual avatars might be collected, e.g. cameras only, motion capture suits, physiological measures such as heart rate, skin conductance and brain waves. Specifically, the question was raised: Which measures help increase fidelity and which ones go ethically too far?

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4.5 Scientific Visualization and VR

Torsten Kuhlen (RWTH Aachen, DE)

Since its hype in the early 90's, Virtual Reality has undoubtedly been adopted as a useful tool in a variety of application domains, e.g. product development, training, and psychology. Yet, one of the proclaimed killer applications of the early days, namely the use of VR technology as an interface for advanced data analysis and visualization solutions, has yet to realize its full potential. While there have been some successes in the research arena, the wide-spread adoption of immersive visualization by domain scientists still hasn't come about. Starting with Andries van Dam's seminal call to action, already published in 2000 in the Computer Graphics & Applications Journal, 14 Dagstuhl Seminar participants discussed several key requirements and challenges for the future development of VR-based visualization tools, specifically targeting aspects of performance, utility, and usability. All in all, the discussion group identified two kinds of primary deficits – interface and system shortfalls. It turns out that VR interfaces developed so far are not well tailored to specific problems and tasks. Actually, domain experts from different areas think differently and have different ideas what they want to do with their data.

Existing VR interfaces do not reflect this issue sufficiently. In terms of system deficits, the group realizes that the available VR tools are not flexible or adaptable enough. Also, they lack interoperability and interactivity/performance. Most of the available frameworks concentrate on real-time rendering only, while for a fully explorative data analysis, an interactivity of the whole visualization pipeline is mandatory, including feature extraction and mapping. Here, we run into a fundamental dilemma for immersive visualization: while its biggest potential arguably is its interactivity, the amount of data that has to be analyzed in any realistically complex application oftentimes exceeds the limits of interactive processing.To make VR more visible and accepted in the communities, success stories should be gathered as a first step, to demonstrate that there already exists a considerable amount of examples where VR tools could in fact assist domain scientists in understanding their data. In the midterm, the VR community should strive to develop better interfaces, tailored to the domain scientists' needs. Thereby, interface development should not only concentrate on large VR systems like CAVEs, PowerWalls etc. Instead, by using commodity I/O devices, VR solutions should be brought to the scientists' offices. In the longer term, a large SW project is most probably necessary to develop powerful VRVis tools. Since VR comes along with quite specific requirements in terms of interaction, latency etc., it does not seem appropriate to just extend existing traditional visualization frameworks. To solve the interactivity-complexity dilemma, a suitable VR-based SW framework will possibly have to leverage supercomputing resources in an interactive way.

4.6 Characterising Interactions in Virtual (and/or Real) Environments

Paul Milgram (University of Toronto, CA)

Our discussion group was motivated by the contention that many researchers in our (extended) community are working on similar or related problems without realising it, while many researchers in our (extended) community think that they are working on similar or related problems that are actually rather different. A number of approaches were discussed about the challenge of how one can go about effectively modelling the various ways in which humans can interact with elements of virtual environments, as well as (in recognition of the importance of mixed reality) with real environments.

A distinction was made between top-down and bottom-up approaches. The former, which are characterised most effectively by parsimonious simplicity, can serve as a powerful means of revealing high level interactions, primarily by means of, among other things, qualitative representations, conceptual relationships, and metaphors. The latter bottom-up models are typically more detailed and serve as invaluable practical tools for describing and developing system architecture.

The conclusions reached included: (a) a consensus that it is indeed a useful exercise to attempt to define a framework for characterising such interactions; (b) no one framework is likely to be adequate for characterising all possible interactions; (c) top-down / conceptual / metaphorical frameworks are typically centred explicitly on users and thus can be difficult / inadequate / impractical for characterising all aspects and components of primarily complex multidimensional systems; (d) bottom-up / algorithmic / structural models are indispensable for software design and development, but are not necessarily useful for elucidating global similarities and differences among diverse interaction systems.

4.7 Unconventional Mixed Environments

Freiherr von Lukas, Uwe; Quarles, John; Staadt, Oliver

The primary objective of the Unconventional Mixed Environments (UCME) session was to discuss the potential for augmented, mixed, or virtual environments whose surrounding real environment is unconventional, e.g., underwater, zero gravity, or extreme pressure. The applications of UCME are potentially very impactful, including rehabilitation, astronaut training, and diver navigation, respectively. However, most UCME applications have been unrealized, perhaps due to limitations in technology and gaps in science.

Currently, there are only a few specific examples of UCMEs, including underwater AR Blum et.al, Zero-G experiments for AR interaction Markov-Vetter et al., and VR installations with additional wind or heat sources. Further installations have probably been done in the military area but have not been published.

In the discussion, we expanded the definition of UCME to two different types:

1. traditional VR or AR installations that shall be situated in a untypical environment
2. VR or AR installations with additional modalities to produce an illusion beyond a classical VR/AR experience (i.e. video, audio, force feedback)

In both cases, we are looking on physical effects such as pressure, temperature, acceleration, density of the surrounding media or flows of media (e.g. wind). Such UCME allow for a variety of specific applications, including training or assistance for divers or astronauts, physical rehabilitation or pain therapy as well as environments for experimenting human behavior (or animal behavior) under special conditions. The implementation of UCME brings up various technical challenges. First of all we have to find robust solutions to make the mixed reality devices resistant to the surrounding environment (water, pressure, extreme temperature, ...). Most of the display systems and sensors used in mixed environments today are designed to work in air. Changing the surrounding medium to liquids, we at least have to adapt the systems or even find completely new approaches. Depending on the state of the art, some of them can be solved with existing technology. However, some of the technical problems will lead to research in mechanical engineering, material science etc. In any case, UCME will have to be addressed by multidisciplinary teams that bring in knowledge from marine technology or aeronautics. For example, it is unknown how to track users reliably underwater.

Besides the technical challenges there are several interesting scientific challenges regarding human aspects. The previous research on how humans perceive and interact with augmented, mixed, and virtual realities (mainly based on the visual channel) must be extended. After understanding the influence of other surrounding media or different modalities for perception of virtual worlds, this knowledge can be applied to build the next generation of more sophisticated UCMEs.

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